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ABSTRACT

The goal of the project was to improve the quality and increase the amount of science knowledge of secondary school life science teachers through a series of workshops and summer institutes using medical school life scientists as the primary vehicle to transfer knowledge to teachers who would then transmit that knowledge to their students. A total of 92 teachers from the Houston (Texas) area successfully completed the program and were provided state-of-the-art knowledge through a multidisciplinary, laboratory course covering cell biology, physiology, microbiology, and biochemistry taught by faculty members from the Baylor College of Medicine. Teacher feedback indicated that new knowledge and skills were transferred to classroom settings and that the program helped strengthen the life science curricula in their respective school districts. This document contains a project overview, background information, a project description and project results for the Fund for the Improvement of Postsecondary Education (FIPSE). Appendices include a sample certificate, course outline, and examples of curriculum materials produced by teachers. (Author/CW)

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ED299137

POST-GRADUATE LIFE SCIENCE INSTITUTE FOR SECONDARY SCHOOL TEACHERS

EXECUTIVE SUMMARY

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
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Robert E. Roush, Ed.D., M.P.H.
William A. Thomson, Ph.D.
Leslie M. Miller, Ph.D.

Project Directors

Division of Allied Health Sciences
Baylor College of Medicine
Houston, Texas 77030

SE 049 642

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Grantee Organization:

Baylor College of Medicine
Division of Allied Health Sciences
One Baylor Plaza
Houston, Texas 77030

Grant No.:

G008302535

Project Dates:

Starting Date: August 15, 1983
Ending Date: August 14, 1986
Number of months: 36

Project Directors:

Robert E. Roush, Ed.D., M.P.H.*
William A. Thomson, Ph.D.
Leslie M. Miller, Ph.D.
Division of Allied Health Sciences
Baylor College of Medicine
One Baylor Plaza
Houston, Texas 77030
Telephone: (713) 799-4611

Fund Program Officer: Dr. Lynn DeMeester

Grant Award:

Year 1	$109,612
Year 2	105,131
Year 3	100,560
Total	$315,303

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* Dr. Roush served as project director with Dr. Thomson during the first two years of the project. During the third year of the project, Dr. Thomson directed the activity with assistance from Dr. Miller.

SUMMARY

The goal of the project was to improve the quality and increase the amount of science knowledge of secondary school life science teachers through a series of workshops and summer institutes using medical school life scientists as the primary vehicle to transfer knowledge to teachers who would then transmit that knowledge to their students. A total of 92 teachers from the Houston-area successfully completed the program and were provided state-of-the-art knowledge through a multidisciplinary, laboratory course covering cell biology, physiology, microbiology, and biochemistry taught by faculty members from Baylor College of Medicine. Teacher feedback indicated that new knowledge and skills were transferred to classroom settings and that the program has been an invaluable asset to strengthening the life science curriculums in their respective school districts.

Robert E. Roush, Ed.D., M.P.H. (Years 1-2)
William A. Thomson, Ph.D. (Years 1-3)
Leslie M. Miller, Ph.D. (Year 3)
Division of Allied Health Sciences
Baylor College of Medicine
One Baylor Plaza
Houston, Texas 77030
(713) 799-4611

Executive Summary

Project Title: Post-Graduate Life Science Institutes for Secondary School Teachers

Grantee Institution: Baylor College of Medicine
Division of Allied Health Sciences
One Baylor Plaza
Houston, Texas 77030

Project Directors: Robert E. Roush, Ed.D., M.P.H. (Years 1-2)
William A. Thomson, Ph.D. (Years 1-3)
Leslie M. Miller, Ph.D. (Year 3)
(713) 799-4611

Project Overview

On August 15, 1983, the U.S. Department of Education, Comprehensive Program of the Fund for the Improvement of Postsecondary Education (FIPSE), awarded Baylor College of Medicine a three-year grant to address the problems of life science education in our secondary schools. The goal of the project was to improve the quality and increase the amount of science knowledge of secondary school life science teachers through a series of workshops and summer institutes using medical school life scientists as the primary vehicle to transmit the knowledge to teachers who can transmit the same to their students. A total of 92 teachers from the Houston-area secondary schools were provided state-of-the-art knowledge and skills through a multidisciplinary, laboratory course covering cell biology, physiology, microbiology, and biochemistry taught by faculty members from Baylor College of Medicine. Teacher feedback indicated that information transfer to classroom settings was not only possible, but an invaluable asset to the strengthening of life science curriculum.

Purpose

The overall goal of the project was to improve the quality and increase the knowledge of life science teachers through a series of workshops and summer institutes. To achieve this goal, the project objectives were as follows:

1. **Develop a series of postgraduate educational experiences in the life sciences for secondary school science teachers that would result in (a) expansion of their knowledge of the life sciences, and (b) provide additional support of their current instructional activities;**

2. **Identify, nominate, and select 108 life-science teachers to participate in the program as Graduate Science Fellows (GSFs);***

3. **Conduct fifteen weekend life-science workshops, three full-time summer institutes focusing on the life sciences, and a series of periodic enrichment activities over the three-year period of the project;**

4. **Evaluate the effectiveness of the overall project in terms of degree of impact on science instruction in Houston schools; and**

5. **Design a model capable of replication nationally by other universities, medical schools, and public school systems that can improve the quality of life science instruction in their respective geographical areas.**

Background and Origin

Building upon previously developed collaborative efforts, Baylor College of Medicine and the Houston Independent School District (HISD) jointly established the goal of improving the quality and increasing the amount of science knowledge of secondary school life science teachers. Prior to offering the workshops and summer institutes, a Content Review Committee was formed to design the overall curricular content for the project. The committee was co-chaired by Dr. William Brinkley, Professor of Cell Biology, and Dr. Robert P. Williams, Professor of Microbiology and Immunology at Baylor, and Miss Marcile Hollingsworth, HISD Director of Science. The other committee members included:

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* Over the 3 years of the program a total of 108 life science teachers were selected from the Houston-area to participate in the program. Of these: 92 (85%) were able to complete all aspects of the project; the remaining 16 teachers (15%) completed portions of the activity.

(a) five HISD life science teachers; (b) Baylor basic science faculty members who served as the life science coordinators for the project; (c) the project's management group; and (d) Dr. Gene Chiappetta, a science education professor from the University of Houston.

Project Description

The mechanism to achieve the partnership between Baylor scientists and HISD teachers involved two interrelated components. The first component was fifteen, one-half day workshops (five per year) focusing on the life sciences. These workshops were designed by the Content Review Committee to provide advanced learning experiences in the life sciences and to prepare participants for the second component of the program. The second component was the offering of three, six-week summer institutes entitled "Post-graduate Life Science Institutes for Secondary School Teachers" which were followed by reinforcement activities during the school year. The workshops and institutes were designed to provide advanced instruction for up to 36 science teachers per year selected from Houston-area secondary school campuses, grades 7-12. The selected participants were referred to as Graduate Science Fellows (GSFs). The four content areas covered by the workshops and summer institutes were: cell biology; anatomy/physiology; microbiology; and biochemistry. Approximately one-half of the summer institutes was spent in laboratory settings which provided teachers with hands-on experiences and direct exposure to science process skills. Upon successful completion of the summer institute, the GSFs were awarded six hours of graduate credit in science by Baylor College of Medicine and were awarded a certificate for their participation. The complete course outline and a sample of the certificate that was awarded are contained in Appendix A and B.

The principal activity undertaken at the outset of the project was the development, implementation and evaluation of a series of educational experiences in the life sciences for secondary school teachers (Objectives 1-4). These experiences were developed by the project's Content Review Committee that has representation from Baylor, participating school districts, and in project years two and three GSFs who successfully completed the program.

During each year of the project, the Content Review Committee reviewed and analyzed in depth: (1) life science curricula offered by HISD and surrounding school districts; (2) the quality of life science instruction in the Houston area in terms of students' composite science scores; (3) the qualifications of life science teachers; (4) resources available to support instructional activities in the life sciences (classrooms/laboratories, laboratory equipment, student manuals, etc.); and, (5) the status of current recommendations for the improvement of life science education within the state and the nation. These meetings proved extremely informative and valuable in planning for and improving the fifteen workshops and three summer institutes.

Five workshops were held during each year of the project. The primary objective of the workshops was to build upon the existing knowledge of the life sciences held by the GSFs, gain their input with regard to what should be included in the six-week summer institute, and prepare the GSFs for continued learning activities during subsequent years of the project. In addition, the workshops were used to gather perceptions of the participating GSFs regarding their individual needs for improvement in the life sciences. Data were also gathered concerning how each GSF felt about their school district's life science curriculum.

The workshops held during each year of the project were well received by the GSFs and provided evidence that the planning efforts for the project had been successful. The GSFs reported, through written evaluations and informal discussions with project staff, that the topics and demonstrations presented were "on target" with respect to what they needed to be covered and expanded upon during the six-week summer institute. The workshops also demonstrated to the Baylor faculty that the GSFs selected for the project were a dedicated group of professionals who were committed to improving the quality of life science instruction in their respective schools. The determination of the final life science content for the six-week summer institute each year was made by the Content Review Committee based on planning session, the workshops held, and discussions with the participating GSFs.

The six-week life science institute was divided in two three-week segments. During the first three-week segment Microbiology and Biochemistry were taught. During the second three-week segment Cell Biology, Anatomy/Physiology were presented. The daily format (9:00 AM-4:00 PM) for each three-week segment typically involved: lectures, practical demonstrations, and laboratory instruction for each of the subject areas. Teachers were tested at the conclusion of each segment and grades awarded based upon performance.

During the three years of the project, 108 teachers were selected to participate in the program as GSFs (Objective 2). Of these, 92 successfully completed the program.* The workshops and summer institutes were formally

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* Sixteen teachers elected to leave the program for a variety of reasons: most citing their summertime commitments, personal illness and illness in the family; however, two chose not to participate in the summer institute due to perceived academic difficulty and one teacher was dismissed from the program.

evaluated by the GSFs. They indicated that the program and the material presented had been: (1) useful to them and their students; (2) relevant, logically sequenced, and well presented; and, (3) consistent in that the laboratory sessions complemented the lectures given.

A second, complementary activity subsumed under Objective 2 was to extend the enhancement process beyond the initial project year (1983-1984) and to actively involve GSFs who completed the program in the program in the enrichment activities of the GSFs who followed in years two and three. This component of the program was and continues to be multifaceted and includes participation in local school district in-service programs, development of innovative instructional materials and resources for classroom use, and preparing additional content lectures and laboratory experiences at Baylor. The activities associated with this component of the program have involved all members of the project staff, school district instructional/administrative personnel, other academicians from Baylor, and the GSFs.

Project Results

The FIPSE project spanned three years which permitted: (1) incorporating feedback from teachers and faculty into the following year's program; (2) establishing and maintaining a science teacher network through scheduled activities attended by all FIPSE participants; and (3) continuing the program after FIPSE funding ended in response to area science teacher demand.

The FIPSE project has made a substantial impact on the quality of science education in Houston-area schools, with many of the results being expected and

others evolving as the project matured. The effects of the project included the following:

- Classroom Curriculum Infusion — The workshops and institutes provided enriched curriculum materials which teachers actively transmitted to their colleagues and students. (A specific example is contained in Appendix C.) Evidence of curriculum infusion has occurred through a variety of measures: (1) teachers reported that the four components of the program were useful in varying degrees, with Microbiology and Cell Biology being the most useful; (2) the HISD biology curriculum was rewritten by FIPSE program graduates incorporating content, materials, and activities gained from the project; (3) biology proficiency test scores of students district-wide increased over the three years of the project; and (4) the project's faculty observed while visiting classrooms that FIPSE-related concepts were being taught. One teacher may have best summarized the impact. **"...not a day goes by that I do not use materials and ideas gained from the FIPSE program."**—Grace Beam, Pershing Middle School.

- Professional Renewal — Teachers expressed verbally and behaviorally a renewed sense of professionalism after participating in the FIPSE project. Twenty-eight FIPSE teachers went on to compete and earn placement in a National Science Foundation mentorship program to further enhance their knowledge and skills. As one teacher stated, **"I gained a confidence in and a respect for myself that I did not have before."**—Carol Weston, South Houston High School

- Collegial Dynamics — Many of the secondary impacts of the project have been derived from the formal and informal interactions of the teachers sharing techniques and content materials with one another. The teacher-to-teacher dynamics positively reinforced the teacher-to-medical school life scientist dynamics. **"Association with other teachers in the follow-up seminars and sharing of ideas gave me even more roads to follow in my teaching practice."**—Barbara Elmore, Jones High School.

- Continuing Impacts — The continuing impact of this project is evidenced by the network of teachers and scientists that evolved and has been maintained and expanded beyond the life of the project itself. "I **realize now that I can continue to expand and enrich what I have learned...I have more questions to answer and activities to try than when I started a year ago."**—Trish Nuno, Clifton Middle School.

The FIPSE project continues to produce a cadre of secondary school teachers with enhanced scientific knowledge who are serving as resources in their respective schools. During the summer of 1987, the life-science institute was continued by Baylor College of Medicine. Twenty-five additional life science teachers from Houston-area secondary schools were trained using the model developed with previous FIPSE funding.

In 1985, the success of the FIPSE project helped to obtain a National Science Foundation award for a three-year initiative in which exemplary teachers of math and science are paired for a one-year learning experience with university scientists who serve as their mentors. One hundred teachers will have been be trained to assume expanded roles as instructional leaders in their schools by the time the NSF project ends in 1987. It is important to note that many of the GSFs have continued their training at Baylor and participated in the NSF-sponsored program for master teachers.

Summary and Conclusion

The success of the FIPSE program for Houston-area life science teachers has been evidenced in numerous ways. The project continues to serve as a vehicle for producing a cadre of secondary school teachers with enhanced scientific knowledge who are serving as resources in their respective schools. With funding by Baylor College of Medicine and from other sources the workshop/ institute model will be continued for Houston-area science teachers.

APPENDIX A

Sample Certificate

Baylor College of Medicine
Center for Allied Health Professions
and the

Houston Independent School District
Division of Instructional Services
award to

Sample

this certificate for outstanding performance as a

Graduate Science Fellow
of the

Summer Institute in the Life Sciences 1984-85
Fund for the Improvement of Postsecondary Education

William T. Butler
President, Baylor College of Medicine

Billy R. Reagan
Superintendent, Houston Independent School District

Robert E. Haun
Director, Center for Allied Health Professions

Maurice Hamington
Director of Science

William G. Thomas
Program Director

Julie M. Rathbun
Program Coordinator

APPENDIX B

Course Outline

MULTIDISCIPLINARY STUDIES in the LIFE SCIENCES for Secondary School Teachers

1985-1986

Sponsored by
BAYLOR COLLEGE OF MEDICINE
Center for Allied Health Professions

Project Directors

Robert E. Roush, Ed.D., M.P.H.

William A. Thomson, Ph.D.

Assistant Project Director

Leslie M. Miller, Ph.D.

Course Coordinator

Peggy Moore

Prepared for:

The Comprehensive Program
Fund for the Improvement of
Postsecondary Education
7th and D Streets, SW
Washington, DC 20202

Date: June 9, 1986
Number: 116BH3056

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Multidisciplinary Studies in the Life Sciences
For
Secondary School Science Teachers

COURSE DESCRIPTION: (BCM 051-501) This course, offered through the Division of Allied Health Sciences, Department of Community Medicine, is a multidisciplinary examination of the life sciences. The course, designed specifically for secondary school life science teachers, integrates current concepts of cell biology, human anatomy, physiology, biochemistry and microbiology. Didactic topics and experimental procedures will include: Microscopic techniques and their application in analysis of structure and function of cells and tissues; study of the structural organization of the human body; mammalian physiology; genetics; energy and metabolism and nutrition; and specific activities of microorganisms to man. The course will be coordinated by faculty from the Center for Allied Health Professions with instruction provided by Baylor faculty members from the basic science fields. Credit is nine quarter hours (or six semester hours).

GOALS: The overall goal of the course is to improve the quality and increase the amount of science knowledge of secondary school life science teachers through a series of workshops and summer institutes using medical school life scientists as the primary vehicle to transmit the knowledge to teachers who can transmit the same to their students. To achieve this goal, the course has been designed to:

1. Provide a series of post-baccalaureate educational experiences in the life sciences for secondary school science teachers that will result in: a. expansion of their knowledge of the life sciences; and b. additional support of their current instructional activities;

2. Develop additional laboratory skills for life science teachers through exposure to laboratory techniques practiced in a biomedical scientific environment; and

3. Expand life science teachers' skills in making careful observations, collecting and analyzing data, thinking logically and critically, and making quantitative and qualitative interpretations.

PREREQUISITES: The course will provide advanced life science instruction for 108 life science teachers selected from the Houston Independent School District and other Independent School Districts within the Greater Houston Area. Under the supervision of each District's Science Director, teachers will be nominated to participate in the course who: 1. are certified by the Texas Education Agency to teach Life Science or Biology in a secondary school setting; 2. who possess a minimum grade point average of 2.5 on a 4.0 point scale for all undergraduate and graduate course work taken; and 3. who have demonstrated instructional effectiveness within their school district as determined by classroom and laboratory observation by instructional supervisors. The qualifications of each participant will be reviewed by an admissions committee of Baylor faculty members. Those teachers meeting the stated qualifications will be invited to participate.

ORGANIZATION OF SUBJECT MATTER: The course involves two interrelated components, a series of life science workshops and a six-week summer institute. The learning experiences have been developed by a Content Review Committee (CRC) made up of Baylor faculty members, HISD and other area independent school district science administrators and science education consultants. The primary objectives of the workshops are to build upon the existing knowledge of the selected life science teachers and to gain their input concerning what should be included in the six-week summer institute. The summer institute is an expansion upon the initial workshops and will provide an opportunity not only to increase participants' knowledge in the life sciences, but to provide practical teaching exercises that can be placed into a secondary life science classroom or laboratory setting.

The membership of the CRC appears on page 3. The CRC has reviewed and analyzed: 1. The life science curriculum offered by HISD; 2. the quality of life science instruction in each district in terms of students' composite science scores; 3. the qualifications of life science teachers; 4. resources available to support instructional activities in the life sciences (classrooms/laboratories, laboratory equipment, student manuals, etc.); and, 5. the status of current recommendations for the improvement of life science education within each district. These meetings were extremely informative and valuable in planning for the workshops and summer institutes.

The subject matter for both components of the course will be organized into the following four modules:

Module One:	Modern Developments in Physiology
Module Two:	Molecular, Cell and Reproductive Biology
Module Three:	Concepts, Principles and Experiments in Modern Microbiology
Module Four:	Biochemistry: An Overview of Functional Concepts

APPENDIX C

Curriculum Materials Produced by Teachers

BAYLOR COLLEGE OF MEDICINE — MEMORANDUM

To: Leslie Miller, Ph.D.
Center for Allied Health Professions

Date: 8/6/86

From: Frank Kretzer, Ph.D.

As per our conversation at the FIPSE graduation program, I am finally sending you copies of the best essay exams produced by the teachers in the 1985 and 1986 FIPSE programs. The take home examination for my 15 hours of lecture was to create five learning activities that exemplified five different concepts I presented. From all these essays, I put together these booklets of "Kretzer-Induced Creative and Modern Science Teaching" which were duplicated and distributed to all members of the class. From what the teachers tell me, these activities have really been utilized in their classrooms. These are complex concepts, but the teachers have brilliantly distilled the "essence of the science" to very creative learning experiences. It is a thrill to see the state-of-tne-art ultrastructure translated into the secondary science classroom.

I also distributed a series of micrographs to each teacher which epitomize the most important points of my lectures. The teachers really utilize this primary data base in tneir classrooms. I have enclosed a few of these micrographs for your information.

FIPSE was a great program. I know that we scientifically updated and infused a renewed enthusiasm in most of the FIPSE participants.

FK:DC

KRETZER-INDUCED CREATIVE BIOLOGY TEACHING

Twenty creative activities reflecting the
concepts of cellular function presented
during the summer of nineteen eighty six

COMPILED FROM THE BRILLIANT FINAL EXAMINATION
ESSAYS OF THE FIPSE 1986 TEACHERS by

Dr. Frank Kretzer
Department of Ophthalmology
Cullen Eye Institute
Baylor College of Medicine

It is hard to visualize the "smallness" with which micro- enabled scientists to study organisms and their structures. U seventh graders, I plan to demonstrate this concept by asking bring various sized spheres to class. We will start out by u basketball to represent the smallest object capable of being the human eye. This will represent approximately 900,000 An We will scale down the sized spheres, perhaps a volleyball, sc baseball, racquet ball to represent the size objects to be see light microscope. This last object, the raquet ball represent smallest object to be seen with the light microscope, or appro 2,000 Angstroms. Lastly would be perhaps a ping-pong ball, a ball-bearing, marble, a B B and a grain of sand, which would r the smallest objects to be seen with an electron microscope, approximately 2 Angstroms.

Editors note: This volleyball to grain of sand gradient demonstrate the morphologic gradient that is so complex to understand. I love t small" gradient.

Editors not
an idea in
the process

Concept: The freeze fracture technique is one way of studying the structure of a cell. Unlike the light microscope and the transmission electron microscope, the exposed fracture faces are observed. Unlike the scanning electron microscope, the tissues are not altered as much.

Level of instruction: 7th grade life science

Type of activity: demonstration

Procedure: Background information would include a description of the other methods of preparing tissue. Photographs taken with different microscopes would have been studied.

To demonstrate the freeze fracture method, take a ball of "Funny Putty" as the cytoplasm. Insert assorted objects for organelles (examples: "Magic Sand" for ribosomes, small plastic balloon sacs for membranous organelles, a bead for the nucleus). Roll into a ball and place in a freezer. (I left it in overnight.)

When cold, the putty can be snapped apart (rather than stretched) and the faces of the organelles will be exposed along the fracture line. As an added bit of drama, brush the surface lightly in one direction with glow in the dark paint (contrast enhancement with gold palladium) and observe under black light.

Editors note: This usage of frozen funny putty brilliantly demonstrates the concept of inert freeze fracture as a tool to reveal protein aggregations in biologic membranes.

Statement: Audoradiography is a technique which has been useful in tracing movement of cellular substances.

In this activity the students will role play the outcome of Paladi's experiment of zymogen movement through the secretory pathway.The activity will demonstrate both conceptually and visually the relationship between time and zymogen movement as well as certain factors of the audoradiography technique.

Question: How do we know that processes such as the secretory pathway actually take place in the cell? What type of experiment would possibly give us the proof we need?

After eliciting possible solutions from the class, we'll discuss Paladi's experiment, including details of the audoradiography tecnique.

Electron microscope photos #6 and #7 will be circulated as examples of what the actual product of audoradiography looks like.

The students will now participate in portraying Paladi's experimental findings of zymogen movement. Six to ten students will place over their chests a black square of posterboard that has been secured around their necks with string.A large Z ,representing zymogen,will be painted with luminescent poster paint onto the the black square. One student will wear a sign saying MITO for mitochondria and one will wear a sign saying NUCLEI

On the black board, held by clips, are signs made with luminescent paint that say RER,PV- peripheral vessicles, CIS, TRANS, CV-condensing vacuoles, ZG-zymogen granuoles, AL -Acinar lumen

Place the students with the MITO, NUCLEI signs off to the side. Have one student wearing a Z stand at random next to one of these students.The rest of the students wearing Zs should be off to the side ready to move into the RER position on the blackboard.

Turn off the lights and begin a fixed interval countdown. After each cumulative countdown,have a student flash a light source along the wall and all of the students wearing Zs should be glowing under the sign RER EXCEPT for the one that has been previously placed elsewhere. How did this zymogen manage to get away from the others? Are they really there at all?

As the exercise progresses place some zymogens under most of the cards on the blackboard.Bring to the class's attention that although most of the zymogens seem to move together, we find zymogens at every point along the secretory pathway. Emphasize to the class that this is an ongoing process and that we have to concentrate on where we find a high concentration of zymogens. If time permits the students can draw a diagram or write a short outline of the Paladi experiment. Someone might also be assigned to research audoradiography and its other uses.

Editors notes: Flashlights reduce the complex idea of pulse chase experiments to graphic stories about movement through discrete cellular compartments.

THE PLASMA MEMBRANE

CONCEPT:

The plasma membrane is a fluid lipid bilayer specific for any membrane type. Phospholipid molecules, with a hydrophilic head and a hydrophobic tail line up in a double layer at the aqueous interface with the tails oriented away from the water and toward each other. (The same orientation is true of other lipids such as cholesterol). Ionic charges on the polar heads porvide an ionic attraction for the attachment of extrinsic proteins. Intrinsic proteins penetrate the hydrophobic core of the lipid layer, some partially embedded, and others penetrate through to the other side becoming trans-membrane proteins. This is possible because the ends of the proteins are hydrophilic (polar) while the parts embedded in the membrane have hydrophobic exposed groups. Glycoproteins are only found on the E face. Proteins move with some freedom in the lipid and can cluster to form multienzyme complexes, to create channels or gates for transcellular transport and to form receptors for molecules.

DEMONSTRATION:
A model to demonstrate the above description of the plasma membrane is diagrammed below. The model is assembled <u>during</u> the course of a class lecture, while the components are identified and discussed. Using this model, the following can be stressed:

1. The fluid nature of the lipid bilayer

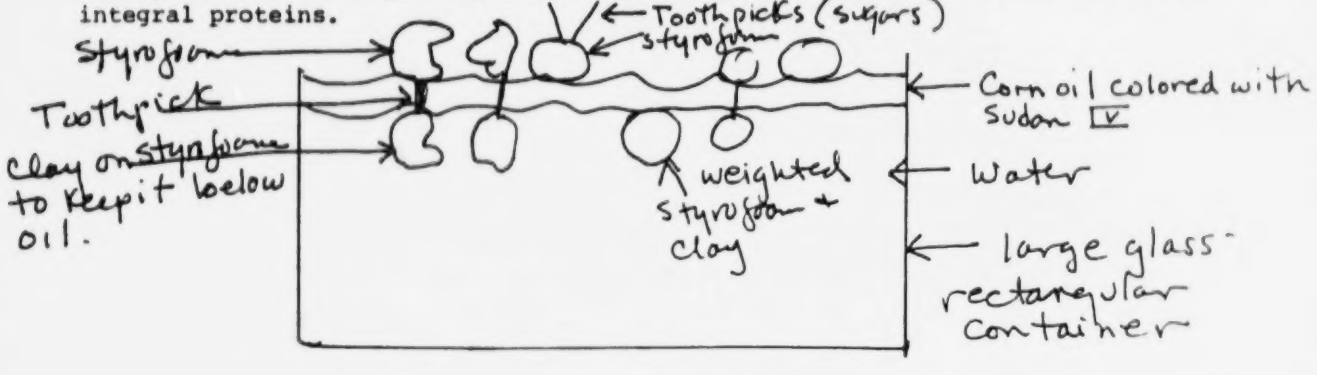
2. The bilayers' hydrophobic qualities. (After adding the fat and it forms a red surface layer, roughly stir the contents of the jar and observe how the surface lipids reform)

3. As the proteins are added define and describe each type: extrinsic, integral, ecto-, endo-, polar and nonpolar sections, transmembrane proteins.

4. Point out the assymetrical distribution of protein on the e and p faces

5. Demonstrate the mobility of the proteins and show how they cluster to form enzyme groups, receptors, channels, etc.

6. Demonstrate the difference in recovery of the extrinsic and integral proteins by removing the extrinsic ones without disrupting the lipid layer, but squirt detergent over the lipid layer causing disruption and so the retrieval of the integral proteins.



Editors note: This floating system shows all the concepts of membrane interactions.

CONCEPT: The plasma membrane is a bi-layer composed of lipid and protein molecules. Due to its composition, the membrane exhibits the characteristics of being fluid, mobile and asymmetrical.

MATERIALS: Tennis rackets will represent the lipid molecules. The racket end is the polar end while the handle and student arm are to symbolize the hydrocarbon tails.

Various lengths of 1" by 8" red boards will represent the proteins.

ACTIVITY: Students with tennis rackets will be lined up back to back in a cellular form. Interspersed in a random fashion will be the students holding the boards symbolizing the transmembrane, ecto- and endo proteins.

Students with the tennis rackets will be instructed to straighten both arms, hold the racket out in front of them, and move as closely as possible to their neighbor. Emphasis will be placed on the fact that the straight arms represent saturated hydrocarbon tails. The question will be posed about the ability of the membrane to move in that condition. Hopefully, the students will realize that fluidity is reduced and the membrane will be in a viscous state.

All the students will be asked to move away from their neighbor just enough to allow room to bend both their elbows. This will be a representation of an unsaturated hydrocarbon tail. How is this composition going to affect the fluidity of the membrane will the question asked and the possible answer should be that the fluidity is increased due to the fact that the molecules find it difficult to pack the chains together.

Now it is brought to the students' attention that some of the lipid chains in the membrane are saturated and some are unsaturated depending on the function. Each student will be told to bend one elbow and become a representative plasma membrane.

How do the lipid molecules move? Some can rotate their polar heads. Students will rotate (twirl) the racket portion of their tennis rackets. Another motion of lipids is movement along their own line and sometimes at a very fast pace. Certain students will be directed to raise their "polar heads" and move to their left beyond the next student. This will be done several times to reinforce the concept.

In which direction have the lipid molecules not moved? Participants should realize they have not changed places or "flip-flopped" with the lipid molecule behind them. Molecules in the plasma membrane rarely do this.

It should be noted that little attention has been given to making the lipid molecules identical in form to the ones behind them. This brings out the fact that a plasma membrane is asymmetrical.

What is the purpose of the proteins in the plasma membrane? From previous study, students should respond that they perform membrane functions, serves as receptors, are enzymes and transporters. A comparison of the relative sizes of the lipid and protein molecules will be made with the proteins being larger.

At the conclusion of this activity, students should have an understanding of the composition and characteristics of the plasma membrane.

Editors note: Lipid dynamics within the membrane are reduced to tennis racket movements. I love it.

The plasma membrane of an eukaryotic cell is made of two components, lipid and protein. The lipid component is called a bilipid layer because the lipid molecules extend side by side in two parallel rows. The two rows of lipid molecules are oriented with their hydrocarbon tails toward the center of the two parallel rows. The protwins are embedded or bonded in this bilipid layer in four different ways. The lipid layer that faces the external environment or adjacent cell is called the E face. The lipid layer that faces the cytoplasm is called the P face. If a protein enters the bilipid layer structure and extends through both the P and E faces it is called a transmembrane protein or intrinsic ectoprotein. If a protein is bonded with the P face it is an intrinsic endoprotein. If a protein is not bonded in the lipid layer of the P face but bonded to it's surface is is called an extrinsic endoprotein. If a protein is not bonded to the lipid layer of the E face but is bonded to the surface (externally) it is called an extrinsic ectoprotein.

METHOD OF PRESENTATION

The lipid bilayer with protein components is very fluid structure. To represent this, two small slinkies are used for each face of the bilyer. Show how fluid the slinkies can be, but at certain points show how the sections (lipid molecules) of the slinkie can "jam up" or the layer can become viscous. At these viscous points the lipid molecules will be tightly held together thus not being able to put any proteins easily into it's structure.

Using small oblong or circular balloons or possibly old marshmallows to represent the proteins, place a protein in the slinkie that represents the P face and ask what kind of protein it is. Take another marshmallow and place it near the P face but not in the slinkie. Take an oblong balloon and insert it within the slinkies connecting them together. Another marshmallow whould be placed near the E face slinkie but not within it.

The terms of intrinsic and extrinsic should be discussed to give some sort of system to naming these proteins. Intrinsic meaning it is within the bilayer not just touching it. The extrinsic term would be applied to proteins bonded to the surface of the P or E face. The ecto- would be used for E face related proteins and endo- would be P face related.

The proteins or marshmallows should be placed in the slinkies more than once to show that these arrangements occur throughout the membrane.

Editors note: Slinkies with marshmallows have transformed the abstract concept of fluidity with sidedness into a concrete reality.

The Incredible Shrinking Membrane

Mitochondria exist in two basic conformational states depending on the degree of ATP formation.

PURPOSE:

To show the students how the mitochondria appear in each of the two conformational states.

Terms to be discussed: orthodox and condensed.

Materials needed:

Fairly good sized piece of wood (12" X 10"), colored yarn, nails, hammer, glue, large rubberband, colored beads.

Set-up:

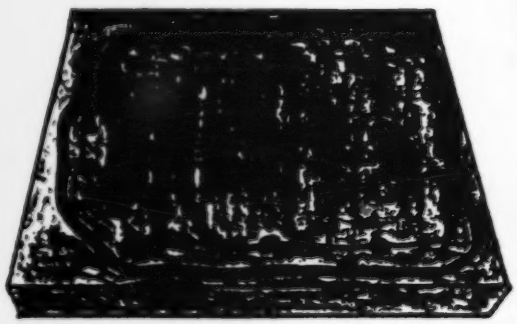
Glue the colored yarn onto the board in such a fashion as to create the outer membrane of the mitochondria. Place a circle of nails along the inside of the perimeter of the yarn. Then move to the center of this configuration and place a smaller circle of nails here. Glue the colored beads to the rubberband. Stretch the rubberband along the outer border of nails. This represents the mitochondria's inner membrane.

Explain to the students that this form represents the orthodox state of the mitochondria. To illustrate the condensed state, simply unhook the rubberband from the outer ring of nails and rehook it on the inner nails. While the rubberband is in this phase, the colored beads (membrane particles) are close together. Explain to the class that when the mitochondria is like this, the matrix is dense.

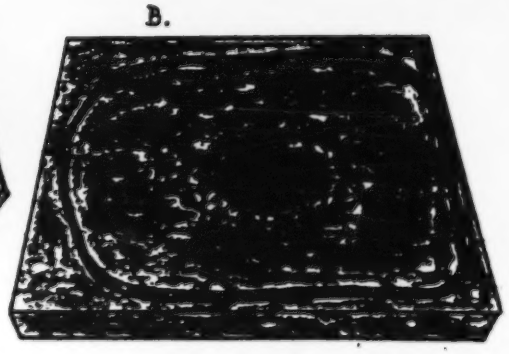
Advantages:

Gives the students a chance to see firsthand that the shrinking of the inner membrane causes the matrix to become more dense.

A.



B.



Editors note: This is a great way of showing the relationship between surface area and the movement of enzymes into multienzyme systems.

CONCEPT: Secreted proteins are created in a process that requires a leader sequence, that occurs in the RER and is carried from there to the Golgi Apparatus to the outside of the cell through the transitional vesicles. A hormone triggers the release of the protein to the outside of the cell.

MATERIALS: The entire room will become a representation of the cell. Students in a line will represent the amino acid chain forming the protein.

Walls = plasma membrane
Desks arranged in an oval = RER
Long rectangular boxes = Golgi Apparatus

ACTIVITY: A set number of students are arranged in a line with each of the first 3 students carrying a leader sign. The last two will carry signs saying carboxyl end; all the ones in the middle carrying balloons with 3 letters representing the amino acids.

The leaders direct the line past the desks (RER) and as they approach a certain section of the desks, the leader signals the next two to arrange two desks so an opening is created. (ribophorin)

Once the entire chain of students is in the oval circle of desks, the two carboxyl ends close the entry pore and the three leaders drop off. The remaining chain of amino acid students move into a very close circle and move in that configuration toward a specified end of the oval. When to that end, the group will put a large balloon (now representing the protein) into the nearest desk. A student will push that desk to an area of boxes labeled the cis Golgi Apparatus where the balloon protein will placed in the cis box and directed to the other end. It will be noted that this particular protein will have nothing added to here as there is no signal for such an addition to occur.

At the far end of the cis Golgi will be a bushel basket marked transitional vesicle. A designated student will catch the balloon protein in the basket and carry it to the next Golgi. This process continues until the entire Golgi structures have been traveled. At the end of this process, the protein will again be in a transitional vesicle.

A student with a hormone label will transfer the transitional vesicle (bushel basket) to an outside door of the classroom. Fitting the bushel basket opening snugly in the door, the door will then be opened and the balloon protein will go outside the cell.

Students should be able to explain the process of making secretory proteins and the role of the leader sequence, RER, Golgi apparatus, transitional vesicles and hormones in the process.

Editors note: The students have been transformed into the secretory pathway. The idea of bushel baskets, balloons, codons, and the door is adorable, yet true to the most current concepts of secretion.

The purpose of this activity is to enable the students to better understand the flow of biosynthetic products through the Golgi complex. The main emphasis will be on the transport of secretory proteins and their outcome of either hormones, lysosomes, or zymogen granules.

A batter of plain sugar cookie dough will need to be made up ahead of time. Several balls of cookie dough will also need to be prepared ahead of time. Use shortening to throughly grease a long narrow column and elevate it. This will serve as a chute for the cookie balls to roll down. At the bottom of the chute you will need a rotating disk, possibly a lazy-susan. Three pans or containers of various mixtures will be needed to sit on the rotating disk. The mixtures represent the three outcomes of the proteins as they pass through the Golgi complex.

As the proteins which are the balls of cookie dough pass through the Golgi complex, the narrow column, they may recieve mannose which could be chocolate chips in one of the three rotating pans and end up being a lysosome or chocolate chip cookie. Another protein could not recieve anything, landing in an empty pan and becoming a zymogen granule or plain sugar cookie. The last example might be a protein recieving a different combination or composition and becoming a hormone or third type of a cookie.

The outcome of this activity is for the student to realize that all three cookies started out as proteins but depending on what combination they recieved as they passed through the sugar factories, the Cis and Trans, is what determined their differences. Each had the potential at the beginning of the Cis to become a lysosome, hormone, or a zymogen granule.

Editors note: This simple example of coating proteins with identifiable tickets graphically makes the concept of Golgi traffic crystal clear.

The Golgi complex is an organelle in the cell that is responsible for the packaging of secretory substances released from the plasma membrane. The protein vessicles arrive from the rough endoplasmic reticulum as transition vessicles. When they arrive at the cisternae of the Golgi they become periphreal vessicles. These periphreal vessicles begin their journey at the cis cisternae. They fuse with the cisternae and the protein enters the cisternae to get a sugar molecule attached to it. It also may pass through the cisternae without receiving a sugar molecule. Whether or not it receives a sugar molecule depends on what type of secretory substance it will be. The vessicle then fuses with each successive cisternae and may receive a sugar molecule. At the last cisternae (trans) the vessicle is complete and will then be secreted from the cell at an optimum time. The extent of the sugar molecule attachment decides what kind of secretory substance it is.

METHOD OF PRESENTATION

The introduction to this concept will be a discussion on the structure of the Golgi complex, it's location near the nucleus, relationship to the rough endoplasmic reticulum and that all secretory vessicles must pass through it before being exported from the cell.

The class will be taken outside to a wide staircase that resembles the cisternae of the Golgi. The bottom step is the cis cisternae and the top step is the trans cisternae. A student will be placed on each step as director of that cisternae. They will be given several balloons of a specific color and shape to represent their sugars. Other students will be dsignated as transitional vessicles (signs or colored cards around neck). They will position themselves on either side of the step and will change their signs or cards to periphreal vessicles. The teacher will then direct them to enter their step and receive a balloon from the cisternae director. They will begin at the cis step. The cisternae director may choose to give them a balloon or not. They will then tie the balloon to their string (protein) and proceed to the next step. After progressing through the entire Golgi and proceeding to each step the periphreal vessicle students will wait at the trans step to be sorted into specific secretion groups. The trans director will sort them into groups by similarity in colors of the balloons they possess on their string. The groups of the same color balloons will be given a secretion name. Those that are released from the plasma membrane will walk to the line designated and release their string of balloons into the air thus secreting their substance. They can release them all at once or one at a time. Some must remain in the area designated as the cytoplasm to release their secretions there.

The secretion groups can be named mucus, hormones, zymogens, lysosomes, etc. depending on how specific the teacher wishes to get. You must also remind the students that not all cells would secrete all of these necessarily.

Editors note: This staircase has become a viable Golgi apparatus adding balloons to proteins to direct traffic.

CONCEPT: Exportable proteins are synthesized and segragated in the cisternal spaces of the rough endoplasmic reticulum.

The Incredible Journey: From polysome to globular shaped protein (to be used as a short answer quiz question)

The following paragraph was written by a student (who shall remain nameless) in an effort to explain protein formation in the rough endoplasmic reticulum. Read the paragraph and underline the words or phrases which should be changed. Above the underlined word or phrase, write the words correctly.

Ribosomes read the rRNA strand form the 3' to 5' end recognizing a non-polar leader sequence beginning with its COOH terminus. This sequence which is a hydrophilic polypeptide attaches the polysome and the +RNA to the rough ER membrane at its E face. As the leader sequence moves through the ribosome pore, extrinsic cross membrane lipids come together to make a ribophorin pore. The leader sequence enters with its COOH terminus first which is cleaved within the cisternal space by an intrinsic ectoprotein, ligase. This enzyme is found in the cisternal space. The amino terminus of the polysome finally passes through the ribophorin pore. This polysome is now really inside the cell. It should be noted that ATP is required for this process. Meanwhile, the ribophorin pore remains in the static lipid bilayer of the ER membrane ready for another leader sequence. The polypeptide can now take on a rope-like appearance.

Editors note: I don't know if I could fix all the errors in this paragraph. It is a great mechanism to get the student to think through the order of the secretory pathway.

Larry Lysosome

Lysosomes are important cellular organelles that have specific functions and characteristics. These organelles are not as simple as they appear to be at first glance. They are many-shaped, they are hard to spot without proper identification techniques, they have two separate exit points from the Golgi Apparatus, and they are unique in that they collect only mannose sugar to make them what they are. Middle school students have difficulty keeping important facts straight, so it is necessary to find ways to help them learn and retain the facts.

Fads can usually be utilized in the classroom with great results. The following is a "rap" to be performed by the students. Most of them are familiar with this trendy type of communication and the catchy beat and phrasing is something that they enjoy. They will gather the facts from the exercise as well as have a chance to vocalize the difficult terms, thus becoming familiar with the vocabulary and the process of cellular digestion.

I'm Larry Lysosome and I'm so cool.
You can see me floating all around this pool.
I'm so important, I've got high status.
You can look for me in the Golgi Apparatus--
In the Cis or Trans, it makes no matter,
'Cause I can blib off the first or wait until the latter.
I pick up mannose to make me sweet--
That little sugar makes me unique!
If you need to be digested, just come on inside,
But don't bust me open or it's SUICIDE!!
My brothers and me are pleomorphs.
We've got more shapes than the seven dwarfs.
Sometimes I'm shy and I hide my face,
But you can always find me with acid phosphatase!
All you heterophagosomes had better run,
'Cause when I catch you, that's when I have fun!
You'll be digested and I'll send your parts far....
All the way down to the Rough E R!
You can be recycled and used by my cell--
And all because of me,now ain't that swell?
After phagocytosis you'll be heading for a fall,
Because that's when the cell gives Larry a call.
I'll come and get you, won't help you to nag,
Because I'm coming for you with my Suicide Bag!

Concept: Lysosomes are important cellular organelles that have specific characteristics and whose main function is cellular digestion.

Editors note: I adore this fusion of science vocabulary, English, creativity, and poetry.

THE FORMATION OF A PRIMARY LYSOSOME

Secretory proteins contained by the rough endoplasmic reticulum lumen are transported by the transitional elements to the Golgi complex for the passage through the cisternae where they are glycosylated in the cis-cisternae and ultimately released by the trans-cisternae and released as primary lysosomes.

Four students are standing in a semi-circular formation representing the RER and holding cut pieces of paper which represent enzymes or secretory products. One of the students collects the cut pieces of paper into a paper bag and leaves the RER group. This student represents peripheral vesicle that was formed by the RER but has budded off.

The peripheral vesicle student walks a few feet with the bag and reaches the Golgi complex represented by nine students, three rows of three students. Each row is behind the other and each row represents a face of the Golgi complex. The peripheral vesicle student approaches the first row , the cis- face group, where he opens his bag and each member of cis-face group drops in one package of sugar. The student then travels by each of the trans-phase members which contribute one small package of sugar to the bag.

When the peripheral student reaches the last group, the maturing-face of the Golgi apparatus, he is told, "You are now released because you are now a primary lysosome! Congratulations!!!!"

Everyone claps, praising the lysosome for his development and freedom to wander around in the cytoplasm. It should be stressed that the traffic of lysosomal enzymes are dependent on specific sugars added to the proteins in the paper bag as the peripheral vesicle student moves along through the Golgi apparatus. *A suggestion for showing selectivity for specific sugars would be to have the students in the Golgi to have both sugar and Sweet-N-Low and to offer the Sweet-N-Low first at which time the peripheral vesicle student would reject their offer only wanting sugar.

Editors note: I love the concept of the Golgi apparatus handing out sugar as well as Sweet-N-Low .

Concept: Lysosomes must remain membrane bound or the cell contents will be destroyed.

Level of instruction: 7th grade life science

Type of activity: laboratory

Procedure: Each group of students will be given two small containers of gelatin or aloe vera gel (more expensive but more convenient) to represent the cell cytoplasm. Each group will than construct a lysosome of thin plastic wrap containing meat tenderizer as the enzyme. The bag will be sealed and placed in one of the containers. Meat tenderizer will be sprinkled directly on the gel in the other container. Students should observe carefully and record what happens.

Related discussion questions should deal with why lysosomes are important in the cell.

Note: It takes only 5 - 10 minutes for evidence of enzyme activity. Results can easily be obtained within a regular class period; containers may be left until the next day in order to see almost total destruction of the gel with the free enzyme.

Editors note: The use of free "meat tenderizer" melts my mind. This is a simple, but absolutely correct analogy.

THE ROLE OF THE PRIMARY LYSOSOME IN DIGESTION
or "THE DEATH OF OLD MAN MITO"

Primary lysosomes aid in the digestion of bacteria and aged cellular organelles by surrounding the organic material and enzymatically digesting the material.

This information could be read as a short story or used as a short skit to illustrate the role of the primary lysosome and eight peripheral vesicles in the destruction of old organelles.

CAST OF CHARACTERS :

Old Man Mitochondria - "Old Man Mito" - one student
Young Tom (the primary lysosome) - one student
The Gang (peripheral vesicles) - eight students
Cut pieces of paper (enzymes)

A short dialogue would need to be written.

SHORT STORY VERSION

Young Tom had only been a primary lysosome for two hours and he was ready for action. He was packed to the hilt with newly made enzymes and feeling somewhat restless.

Now there was talk around the cell that "Old Man Mito", who was now getting very old, had been down right mean to the members of "The Gang". The members of "The Gang" (vesicles) had tried to ignore him but at his age, he had developed a rather bad outlook on life, probably knowing that his days were numbered. Problems kept getting worse between "Old Man Mito" amd "The Gang" and so they decided to tell their problems to Young Tom. Now Young Tom didn't like the idea that his friends were being pushed around by an aging mitochondria who had seen his best days. So, they decided on an attack plan to rid the cell of this aging, unwanted character. "The Gang" surrounded and partitioned off "Old Man Mito" and fused together forming two circles (membranes). "Old Man Mito" was too tired and old by now to put up much of a resistance.

Young Tom moved right in close and fused with the circles "The Gang" had formed. At that moment, Young Tom began releasing his newly acquired enzymes onto "Old Man Mito" and it wasn't but a minute or two before "Old Man Mito" was finally put to rest.

Word has it around the cell, that old organelles should get along with "The Gang" and Young Tom or their existance could be cut short by several days if they don't.

Editors note: A creative story puts molecular biology in terms of human dialogue. I love the story, I love the idea, I love the reality that it conveys.

WHEN IS INSIDE OUTSIDE?

CONCEPT:

Because of their relatively large size eucaryotic cells have a complex profusion of internal membranes. These form extensive intracellular membrane bound organelles and vesicles which are physically and chemically distinct from each other and have compartments each with boundaries of sealed, selectively permeable lipid bilayers. Surrounding these vesicles and organelles ia the aqueous cytosol. Molecules contained within these vesicles are therefor physically separate from the rest of the cell and so are "outside" of the cytosol. Examples of these membranous organelles include the endoplasmic reticulum, the Golgi apparatus, the lysosomes, and other vesicles. Therefor, once a protein molecule synthesized by a bound ribosome is brought into the rough endoplasmic cysterna by a leader sequence, it has effectively left the cell. The following classroom demonstration attempts to make this concept understandable.

DEMONSTRATION:

Basic concept: Once contained within the vesicle, the protein molecule can travel to the cell membrane and be released into the inter-cellular space without ever being in contact with the aqueous cytosol.

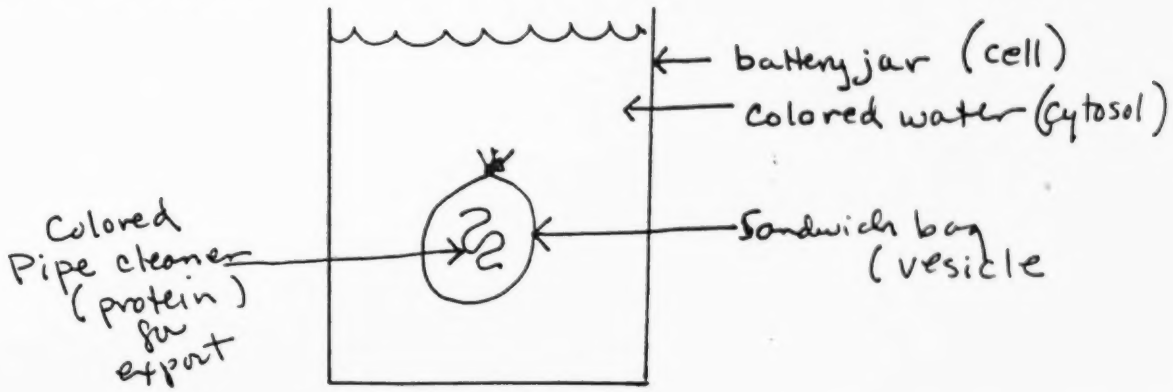
1. The demonstration is set up as shown in the diagram below. Materials needed are: a large battery jar, one good clear sandwich bag (with a wide opening so the bag can be turned inside out), a colored pipe cleaner.

2. Fill the battery jar with water colored a light blue.

3. Place the coiled protein pipe cleaner inside the sandwich bag and blow the bag up holding the top closed with your hands after you have twisted the top.

4. Immerse the bag into the bottom of the battery jar "cell" as shown. Comment on the "outside" nature of the protein molecule.

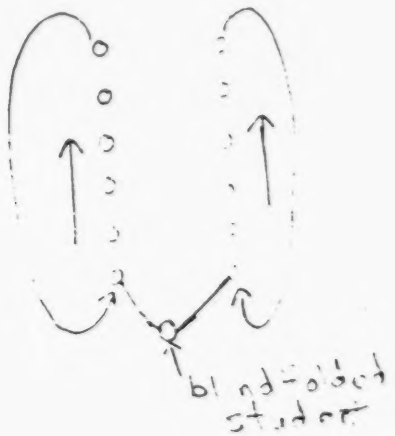
5. Demonstrate exocytosis or reverse pinocytosis by moving the bag to the waters edge, turning the bag inside out at the surface freeing the "dry protein" to the outside.



Editors note: This simple bag exercise makes the concept of inside/outside as simple as a dry pipe cleaner.

Contrary to popular opinion, cytoplasm is not fluid with cell particles floating around. Cytoplasm has many parts which serve to keep particles moving in the correct direction and also to help the cell keep its shape. Microtubules, as an example, are long stiff cylinders, found in the cytoplasm. They pull cell parts along with them from one end of the cytoplasm to the other.

All desks will be moved to one side of the room. One student will be designated the cell particle. He will be blindfolded. After turning student around several times to disorient him, he will attempt to get from one side of the room to the other as quickly as possible. While doing this, the teacher will explain that that is how the old theory of cytoplasmic movement worked. Next the same student will again attempt to travel from one side of the room to the other guided by students lined up in the form of a stiff long tube. One set of students will hold hands with the blindfolded student (forming a bond) and lead him down the tube. As they are moving down the tube, the students on the end will separate and come back to the front (see illustration) to show the treadmilling effect of microtubules. When the student reaches his destination the class will decide which transport mechanism was more efficient. Perhaps they will even be able to see the total elegance of the cells in relationship to their functions.



Editors note: A simple class exercise that makes a very sophisticated point about randomness modulated by microtubules (cytoskeleton).

CONCEPT: The cytoskeleton is a series of microtubules, microfilaments and intermediary filaments working together to give the cell stabiltiy of shape and the ability to move cell organelles within the cytoplasm.

MATERIALS: Upon entering the room, students will be met with the top ½ of the room in a mass of seemingly tangled rope, cable and yarn.

Microtubules: Radiating from near the center of the ceiling will be several double pulley systems which use cable. One end of the pulley will be attached to the centrosome figure in the center of the room and the other to the outside edge of the ceiling tiles. To represent the MAPS, stiff colored fishing line will be put into the cable at a predetermined angle.

Microfilaments: 2 different colors of heavy yarn or thin rope will be twisted together to represent the actin and myosin. This series of filaments will run parallel to the microtubules.

Intermediary filaments: 1 strand of intermediate size cord will be used and several strands of these will radiate from a point on the outside edge of the ceiling tiles. (P domain of the transmembrane proteins.)

ACTIVITY: The students will be presented with 8 problems to solve during the course of the activity.

1. Without using the hands, what structure would enable the microtubules to move? (MAPS)
2. What direction do these structures in #1 force the microtubules to travel? (from center to the outside)
3. What does the use of a pulley tell you about the movement of the microtubules? (treadmilling)
4. How many major proteins will make up the microfilaments? (2)
5. What can the major proteins in the microfilaments enable the structure to do that can't be done in the microtubules? (Contract and bundle)
6. If you put a bucket (transitionsal vesicle) on the microtubule, what would the microfilaments possibly do to get out of the way of the bucket? (Bundle)
7. Put the three structures in order relative to size from the largest to the smallest. (tubules, intermediate, filaments)
8. Getting a clue form the name, which structure is created from 13 rigid cylinders arranged in a circle with an opening in the middle? (Microtubules)

Upon completion of the 8 problems, a discussion and demonstration of the principles will follow. A 3 dimensional model of the microtubules will be presented. This will include several segments of a paper towel tube with 13 pieces of dowel rod glued on the outside. The segments of tubing will slide onto a metal tube.

In conclusion, students will be able to describe the structures found in the cytoplasm of the cell which provide structure.

Editors note: The 3-D classroom has become a meshwork of working cytoskeleton. No student will ever forget this happening.

TREADMILLING AND SPATIAL CONTROL BY TUBULIN POLYMERS

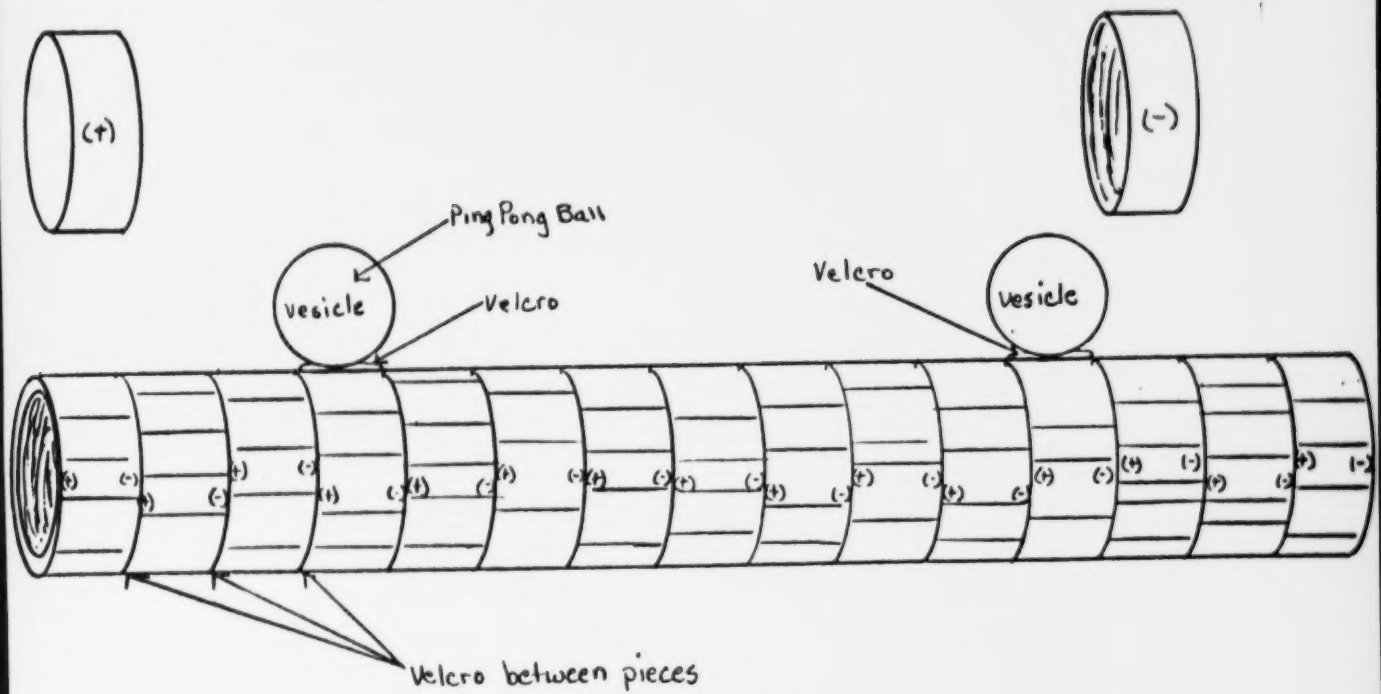
CONCEPT : Microtubules can act as a structural framework of the cytoskeleton or participate in cell movement. Microtubules in the interphase cell radiate out from the centriole or cell center. The tubulin protein molecules form a hollow tube, and as more tubulin molecules are polymerized to the central (+) end of the microtubule, tubulin molecules are depolymerized from the (-) end. The attachment of accessory proteins to the tubulin molecules provides steady movement of proteins by treadmilling. The capping proteins provide a mechanism of microtubular extension and retraction, as is needed in microvilli extension and retraction.

ACTIVITY : PVC pipe of 2" diameter will be painted lengthwise with acrylic paint lines (13 different colors) to represent the 13 molecules of tubulin forming the tubular structure. The painted pipe will then be cut into 1" long pieces, (+) and (-) painted on each end of each piece for polarity, and velcro applied to each end of each piece to attach the "molecules" of tubulin to each other. Ping pong balls with labels indicating packaged proteins will have a velcro spot for attachment to the "tubulin" rings. Several of the tubular pieces should also have a velcro spot on the outer surface as an attachment for cytoplasmic proteins. Treadmilling can be demonstrated by the students by having them attach the "protein" ping pong ball to a newly (polymerized) added ring and then having them continue to polymerize and depolymerize the ends of the microtubule by adding and taking off rings of "tubulin" at the appropriate ends.

Protein capping at either of the (+) or (-) end of the microtubule can be demonstrated by PVC caps labeled (+) and (-), corresponding to the microtubule ends. Extension can be demonstrated by having a student "cap" the distal (-) end of the microtubule while another student continues to "polymerize tubulin" at the (+) central end of the microtubule by adding rings. The reverse condition of microtubule vanishing can be simulated by students "capping" the central (+) end of the "microtubule" while students continue to "depolymerize tubulin" at the (-) end by removing rings. Students will therefore be able to see the polarity of the tubulin molecules as well as that of the microtubule, and the 13 molecules which comprise the rings of the microtubules. They will be able to see how proteins move through the cytoskeleton by consistent treadmilling, as well as how a cell can retract and expand itself by capping proteins..

This "microtubule" could be used in a larger PVC pipe cut open lengthwise, and rubber-banded shut for storage.

Editors note: I loved the use of 13 colors of paint, velcro, and a model that can really work.


(+)
(-)
Ping Pong Ball
Vesicle
Velcro
Velcro
Vesicle
Velcro between pieces